Results of Erosion Analysis of the Clear Creek Road Network

Nez Perce-Clearwater National Forest

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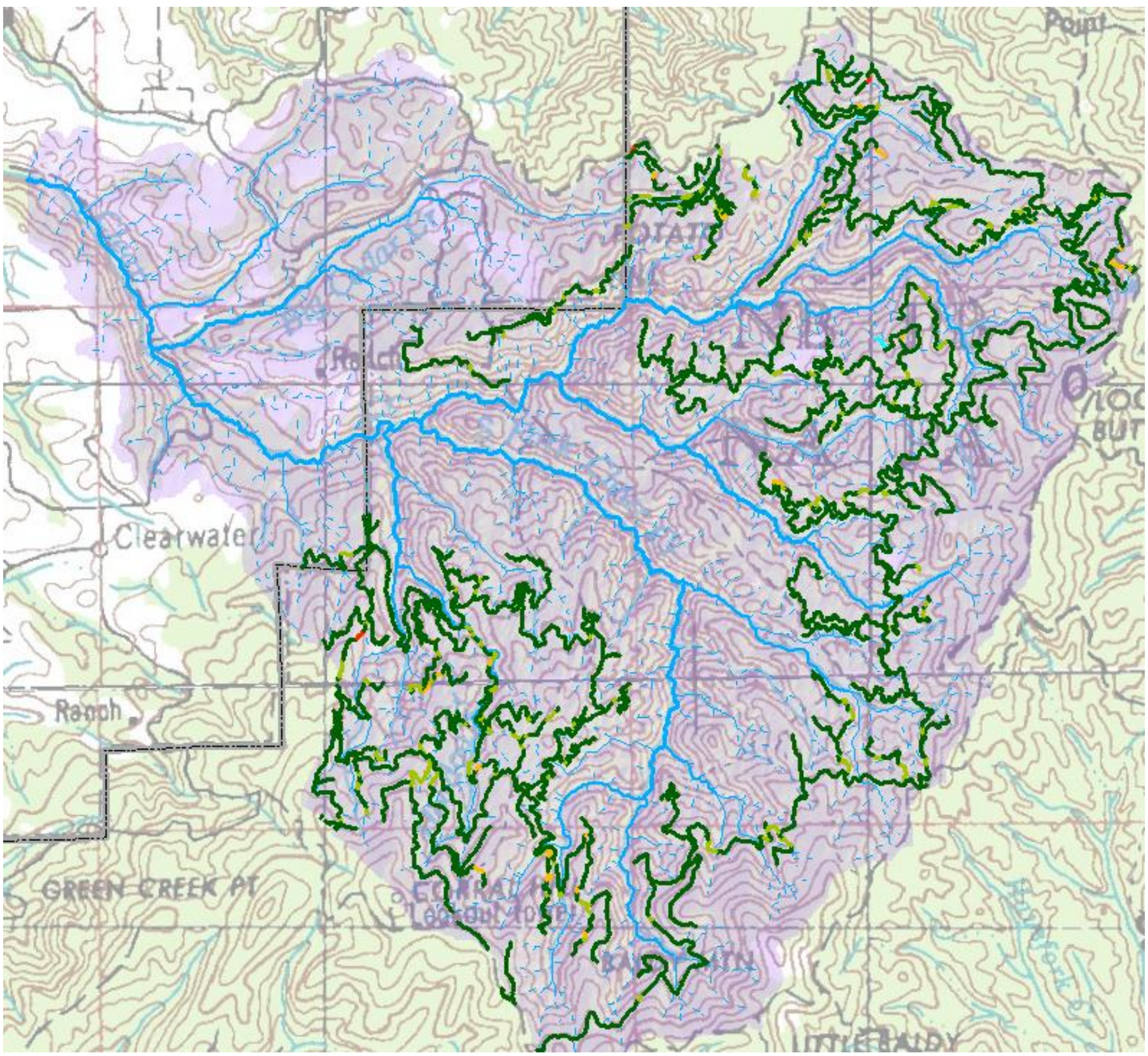

Background

The Nez Perce-Clearwater National Forest (NPC) is planning a major restoration project to improve forest health and decrease the risk of wildfire in the 178 km^2 (68 mi^2) Clear Creek Watershed, southeast of Kooskia, ID (Moose Creek Ranger District, 2015). Elliot and Miller (2017) provided a detailed analysis estimating likely erosion from the proposed treatment areas, but at that time, did not have the tools to satisfactorily estimate sediment from the road network. Roads play a critical role in allowing access to the forest for the proposed treatments. However, the road network is the main source of sediment in most forested watersheds in the absence of wildfire (Elliot, 2013; Grace, 2017). Earlier estimates of likely road sediment generation were made with the NezSed cumulative effects model, which was not able to consider erosion from individual road segments. When Dr. Cao joined the research team, we were able to develop the methodology described below to complete a road network erosion analysis. This report is an example of applying this new methodology and evaluating its utility to support watershed analysis.

The Water Erosion Prediction Project (WEPP) was used to predict sediment delivery from each road segment. The modeling approach is based on the template used in the WEPP:Road interface that estimates erosion on the road surface and sometimes the fillslope, and then sediment delivery from runoff that is routed from the road surface, over the fillslope, and through a forested buffer before reaching live water (Figure 1[1]; Elliot, 2004). The WEPP model is a complex physically-based computer program that models the processes that cause erosion, like runoff, sediment detachment, sediment transport and sediment delivery. It is run on a daily time step, and estimates the sediment delivery for each runoff event for a period of years ranging from a single storm to 999 years of daily climate. The WEPP:Road online interface is designed to allow users to easily describe the topography and road management for the elements shown in Figure 1. Management options include road traffic level (none, low or high), road surface design (insloped to bare or vegetated ditch, and outsloped with our without ruts) and road surface treatment (native, graveled or paved). Because most managers need to know the

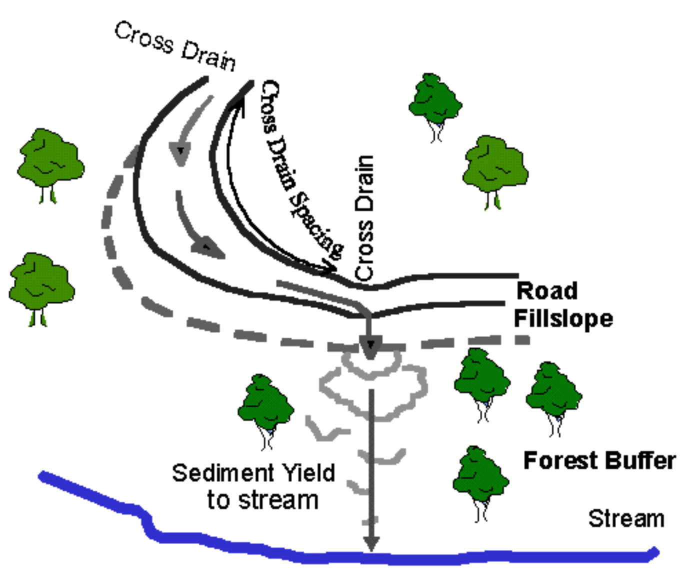

Figure 1. Template assumed for the WEPP:Road interface with sediment generated by the road surface routed over a fillslope and through a forest

[1] https://forest.moscowfsl.wsu.edu/fswepp/docs/wepproaddoc.html

Table 1. Crosswalk between the NPC road category and the segment attributes for WEPP:Road.

	WEPP:Road Attributes			
NPC Road Category	Design	Surface	Traffic Level	Width (ft)
Asphalt and passenger cars	Inslope, Veg Ditch	Paved	High	18
High clearance vehicles	Rutted	Native	Low	10
Improved native material	Rutted	Native	Low	12
Crushed aggregate or gravel	Inslope, Veg Ditch	Gravel	High	16
Native material	Rutted	Native	Low	12

delivery from hundreds or even thousands of road segments, a batch interface (WEPP:Road Batch[2]) was developed to receive topographic input values from spreadsheets or databases and estimate the sediment delivery from hundreds of road segments at a time.

Soil erodibility properties are highly variable with coefficients of variability (measured erodibility standard deviation divided by the erodibility mean) typically around 30 percent (Elliot et al., 1989). This means that at best, there is a 90 percent likelihood that an erosion value estimated by any model is within plus or minus 50 percent of the true value. No model can be any more accurate than the variability of the input data allows.

Methods

A GIS layer containing the road network in the watershed was provided by the NPC. The NPC road network data had five categories of road use (Table 1). Each category was linked to road attributes required by the WEPP:Road interface. A cross walk spread sheet was developed with logistic functions to assign the WEPP:Road attributes to each NPC road segment category. For each NPC road category, we assigned a “design”, “surface”, “traffic level” and road width as required by the WEPP:Road Batch Interface ((Table 1; Elliot, 2004; Brooks et al., 2006).

With GIS, we followed the topographic analysis methodology developed in Cao and Elliot (2018) to subdivide the NPC road network into hydrologic segments, identify cross drain outlet locations and determine the overland flow path from the road outlet to the nearest likely cell with concentrated flow. The Cao and Elliot method then determined hydrologic segment lengths and gradients, and the length

[2] https://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/wr/wepproadbat.pl

and steepness of each respective buffer. We assumed a maximum distance between cross drains to be 100 m (305 ft).

In ArcMap 10.3, a 10-m DEM was used to generate the hydrologic segment topographic details that were merged with WEPP:Road attributes in a spreadsheet, with one row for each hydrologic segment. From the merged data, columns in the spreadsheet were added to exactly match the WEPP:Road Batch input table. From this spreadsheet table approximately 800 road segment rows were then copied and pasted into the WEPP:Road Batch online interface. We assumed a silt loam soil category and used weather statistics from the nearby Fenn Ranger Station, located 13 km northeast of the watershed to generate a stochastic weather file. Because of timeout limitations with the internet browser when running large numbers of road segments, the model was simulated for only 15 years of stochastic climate for each road segment (instead of a recommended 50-100 years).

The output tables from each of the WEPP:Road Batch runs were copied and pasted back into the spreadsheet where the results could be summarized, and linked back to the original GIS containing the road network. In GIS, the stream order and road erosion, sediment delivery, and buffer deposition rates were classified to aid in visualizing where the segments with the greatest risk of erosion and sediment delivery were located. Additional summary calculations were carried out in the spreadsheet.

Results

There were 3276 individual road segments identified in the GIS analysis (Table 2), totaling nearly 300 km (186 miles) in length. The total estimated amount of sediment leaving the roads was 774 Mg (852 tons) and the estimated amount delivered to the stream system was 278 Mg (306 tons). 80 % of this sediment was delivered from only 50% of the road network. At least 1 kg of sediment was delivered from 93 % of the road segments.

From the results in Table 2, the estimated road surface erosion rate in the units used in the NezSed Model, is 1573 tons mile^{-2}, compared to the NezSed values of 18,000 tons mile^{-2} for “exist” roads and 5,000 tons mile^{-2} for minor, new, major, moderate, temporary and “decomy1” roads. The NezSed values are reduced within the model to incorporate sediment delivery and time since construction or reconstruction.

Figure 2 shows the amount of sediment leaving the road surface for each of the 3276 road segments. A larger number (denoted by the color red) suggests that this segment has a high estimated erosion rate, likely due to a long segment or a steep segment.

Figure 3 shows the amount of sediment reaching the stream (Figure 1). Note that the erosion category range is reduced with the highest delivery rates about a third of what they were for road segments.

Figure 4 shows the difference between the amount of sediment leaving the road and the amount delivered to the stream. A large positive value indicates that the buffer is a location of deposition. A negative value suggests that the buffer may be eroding.

Map packages for Figures 2, 3, and 4 are available on the Pinyon Drive[3] (Appendix), as is the spreadsheet with all of the NPC category and WEPP:Road Batch input and output data for each segment. The

[3] https://usfs.box.com/s/go9hy4r4uprn1ncngqdmojkrydb80qo7 ; Contact suemiller@fs.fed.us for access.

Table 2. Summary of road network erosion analysis for the NPC Clear Creek Watershed.

	Metric	English
Average Annual Precipitation	960 mm	37.7 in.
Average Annual Runoff from rainfall	5.46 mm	0.21 in.
Average Annual Runoff from snow melt or rain on snow	5.25 mm	0.21 in.
Total Runoff	10.71 mm	0.42 in.
Total length of road	299 km	186 miles
Number of road segments	3276	
Average segment length	91.3 m	299 ft
Average segment gradient	4.63%	
Average width of road segments	4.69 m	15.38 ft
Average buffer length	64.1 m	210 ft
Average buffer steepness	30.4%	
Total sediment leaving the road surface	774 Mg	852 tons
Total sediment delivered to the stream	278 Mg	306 tons
Calculated Sediment Delivery Ratio	0.36	
Average road erosion rate per Km and Mile	2.59 Mg/km	4.59 tons/mi.
Average sediment delivery rate per Km (mile)	0.93 Mg/km	1.65 tons/mi.
Average surface erosion rate	5.52 Mg/ha	2.46 t/acre
	552 Mg/km^2	1573 t/mi^2
Road density	1.66 km/km	2.7 mi/mi
Road sediment delivery per watershed area	2.8 Mg/km^2	8 tons/mi^2

spreadsheet can be linked to the ArcMap files in two ways. If the user notes a road segment on the spreadsheet and wants to find it on the map, make a note of the “ORIG_FID” in column AO on the spreadsheet. Open the desired ArcMap file (Road_Erosion, Road_Buffer_Erosion, or Road_RD-Buffer-Diff), right click on the CC_roads-WEPP_Rd_Runsxxx line in the Table of Contents, and open the attribute table. Search the attribute table for the desired ORIG_FID value and select its line. The segment will then be highlighted on the map. The user may find it helpful to highlight several lines around the desired one to better find the general area on the map before highlighting a single line only.

To find the results for a given road segment on the map, select the Identify button and click the desired segment. On the table of information about the segment that is presented, note the ORIG-FID, and find the line on the spread sheet for that segment in column AO. There are other ArcMap methods that can also be used to link the spreadsheet to the map for users who are familiar with ArcMap.

When interpreting the spread sheet results for road segment lengths, be careful to use the original input lengths from the NPC. The output lengths from WEPP road have been truncated during processing, and will result in an underestimation of road segment lengths.

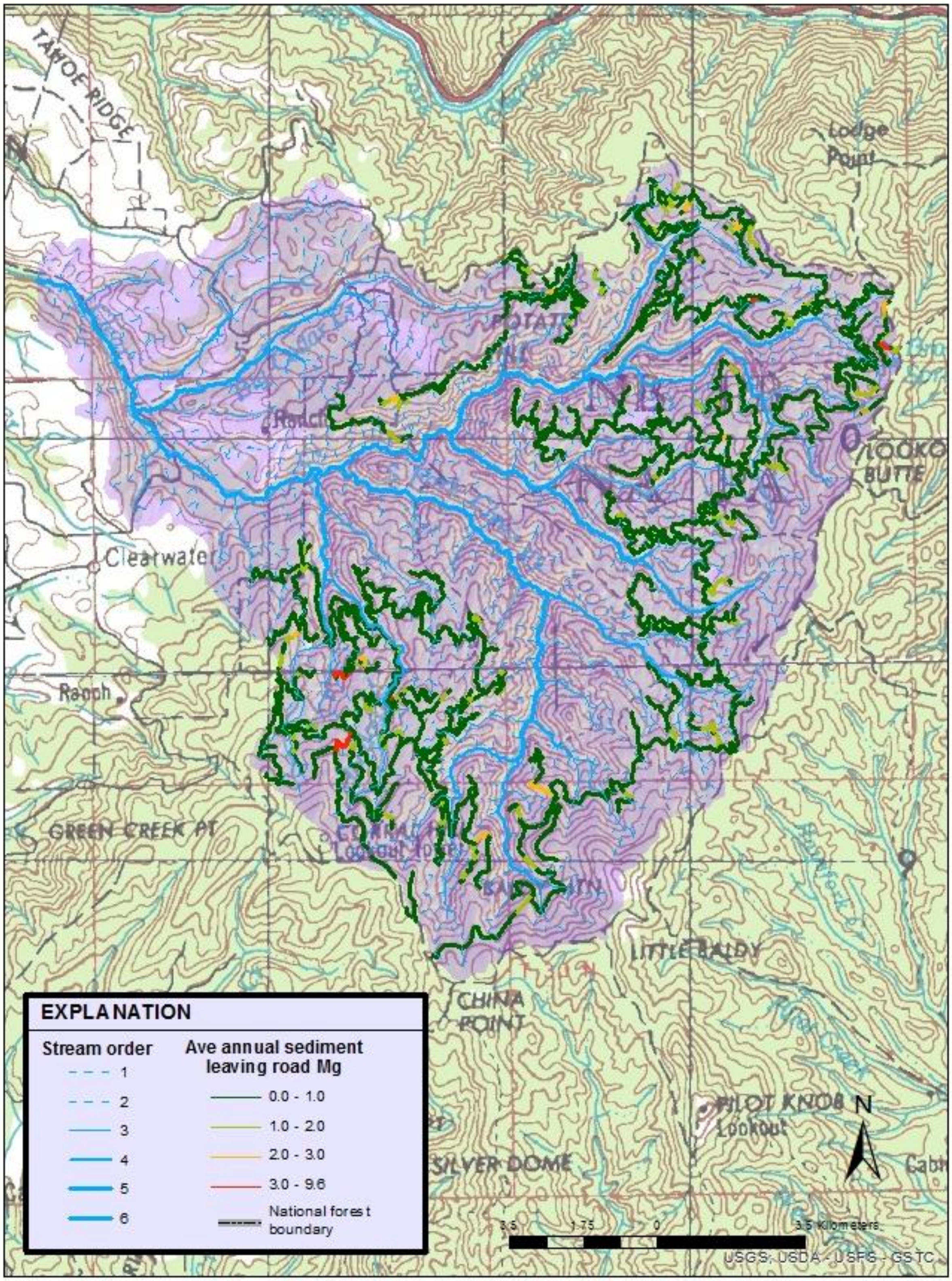

Figure 2. Estimated road surface erosion in the Clear Creek Watershed, Nez Perce-Clearwater National Forest.

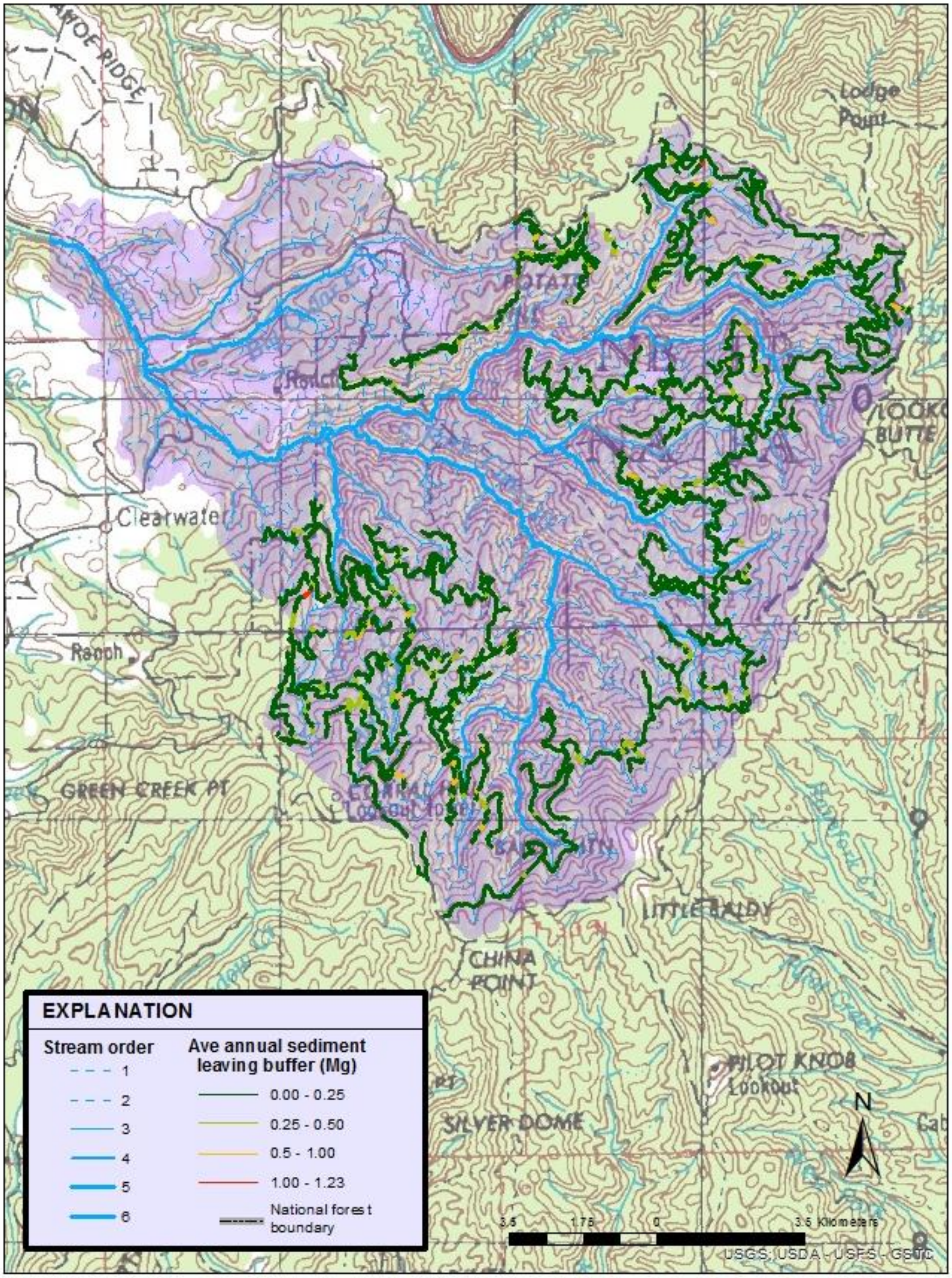

Figure 3. Estimated sediment delivered from the road buffer to the nearest cell with concentrated flow in the Clear Creek Watershed, Nez Perce-Clearwater National Forest

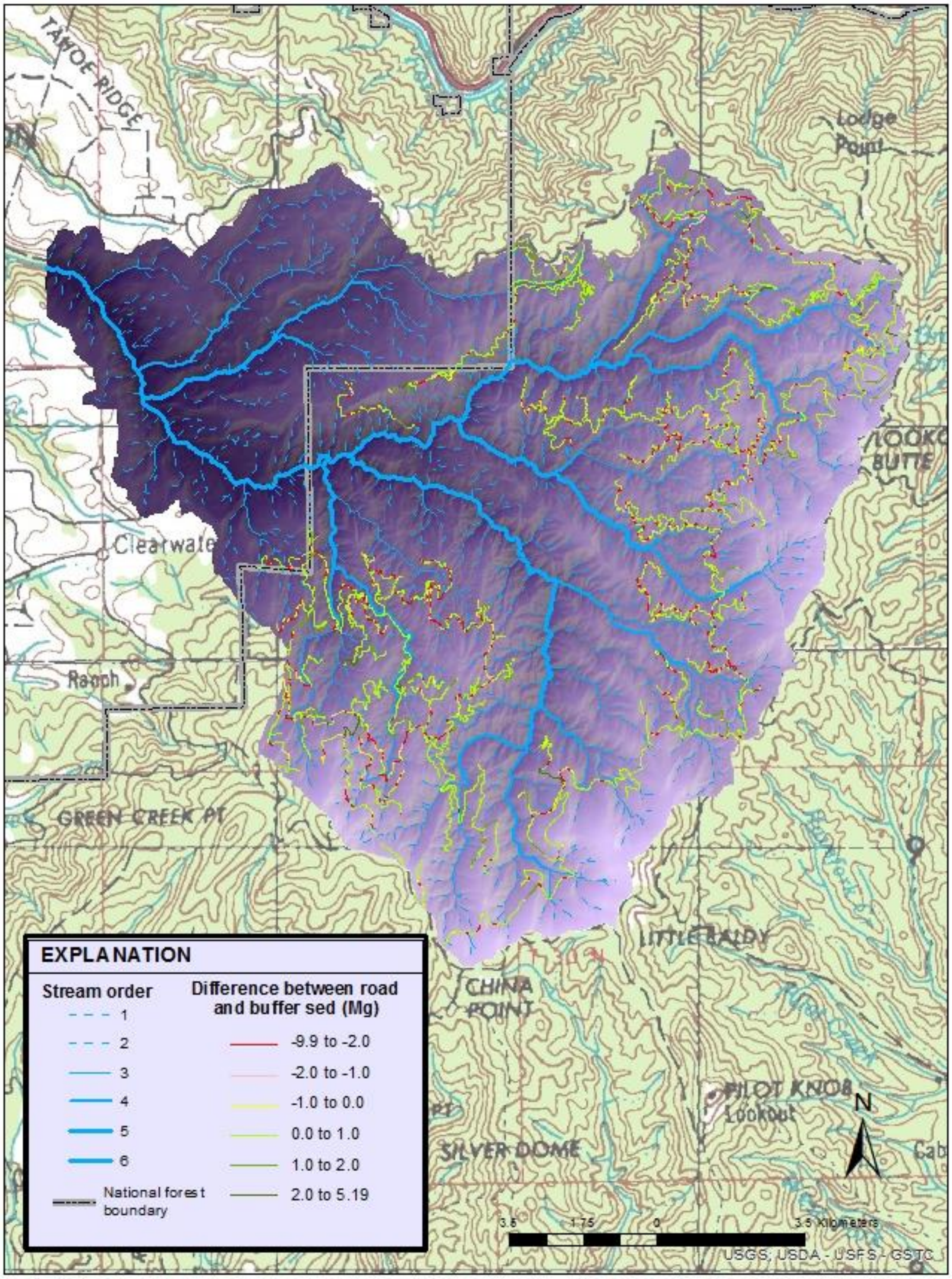

Figure 4. Difference between the estimated amount of sediment leaving the road and the sediment interesecting concentrated flow in the Clear Creek Watershed, Nez Perce-Clearwater National Forest. A large positive value suggests that the buffer is an area of deposition. The negative values indicate that the buffer may be eroding

Site Visits

RMRS scientists visited the Clear Creek Watershed on five occasions. The first trip was in September 2016 with local specialists to get an overview of the watershed management plan and collect data from the Forest for a watershed analysis (Elliot and Miller, 2017). The second visit was in October, 2016 to attend a meeting with a number of stakeholders and make a short presentation about the overall watershed analysis. In January, 2017, we met with the NPC watershed team at the Moose Creek Ranger Station to give a presentation of our forest management modeling results (Elliot and Miller, 2017), and to discuss our approach to modeling erosion of the road network.

The fourth site visit was in June, 2017, to make onsite road gradient observations of select road segments to compare to LIDAR and other GIS gradient estimation methods. Specific road segments were identified prior to the field visit. In the field, road segments lengths were measured with a tape, and differences in elevation between the ends of the segment were measured with a laser level (Figure 5). The gradient was the change in elevation divided by the segment length. The field observations confirmed that the GIS topographic analysis methods were valid, and could be applied to the larger road network for subsequent erosion analysis. Figure 6 shows that the GIS methodology accounted for 84 percent of the variability in road gradients observed in the field.

A final visit to the site occurred in June, 2018. The purpose of this visit was to confirm the generally low erosion rates for most road segments, and to specifically look at some selected sites that initial analyses had identified as potentially problematic. At the same time, all roads traversed to access the sites could also be inspected. Figure 7 shows the location of the four sites that had been selected.

Figure 5. Measuring the length and steepness of a road segment in the Clear Creek Watershed in June, 2017, to support the development of a GIS topographic analysis technique for analyzing the larger road network.

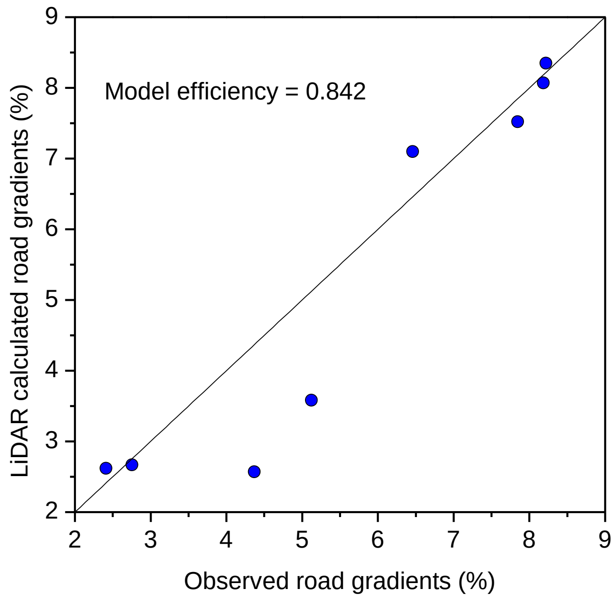

Figure 6. Comparison between the observed and LIDAR-calculated road gradient

Generally, there was no evidence of erosion on the road surfaces (Figure 5). There was some evidence of soil displacement, either erosion or deposition, in road ditches (Figure 8), particularly where road gradients were steeper. All of the main roads were graveled and showed no signs of surface rutting (Figure 5), and the side roads were vegetated so there would be minimal erosion risk (Figure 8).

At site 1 (Figure 7), we found that the road had not been used for many years (Figure 9). There was evidence that in the past it had experienced severe erosion both onsite and offsite, but it was now totally covered in trees that were estimated to be 20 years old. Even in its current condition, it was still concentrating upslope runoff, and was a potential risk for initiating a debris flow (Gorsevski et al., 2006). Should this segment be reopened, enhanced management practices may be needed to limit surface erosion and offsite sediment delivery.

On site 2 (Figure 7), the road had been recontoured and so was no longer a surface erosion risk (Figure 10). The only concern for this site was that the recontouring was on a steep hill adjacent to Hoodoo Creek, so there was a potential that legacy compacted road layers in the soil profile could result in a landslide (Elliot et al., 1996). If the old road surface was removed or scarified as part of the recontouring then the risk of a landslide is minimal.

Both sites 3 and 4 were vegetated so erosion risk was minimum (Figure 8). There was some evidence of soil displacement in the ditch at site 3, but no signs of surface erosion at site 4.

Discussion

By only running the model for 15 years of stochastic climate, rather than 50 or 100 years, it is possible that there may be underestimation of sediment delivery. The underestimation, however, will be within the plus or minus 50 percent accuracy range associated with any soil erosion model. Figure 11 shows that for a typical 60-m long road segment with a 40-m long buffer, the predicted sediment delivery for a 15-year WEPP:Road run is within the error range for a 100-year long run.

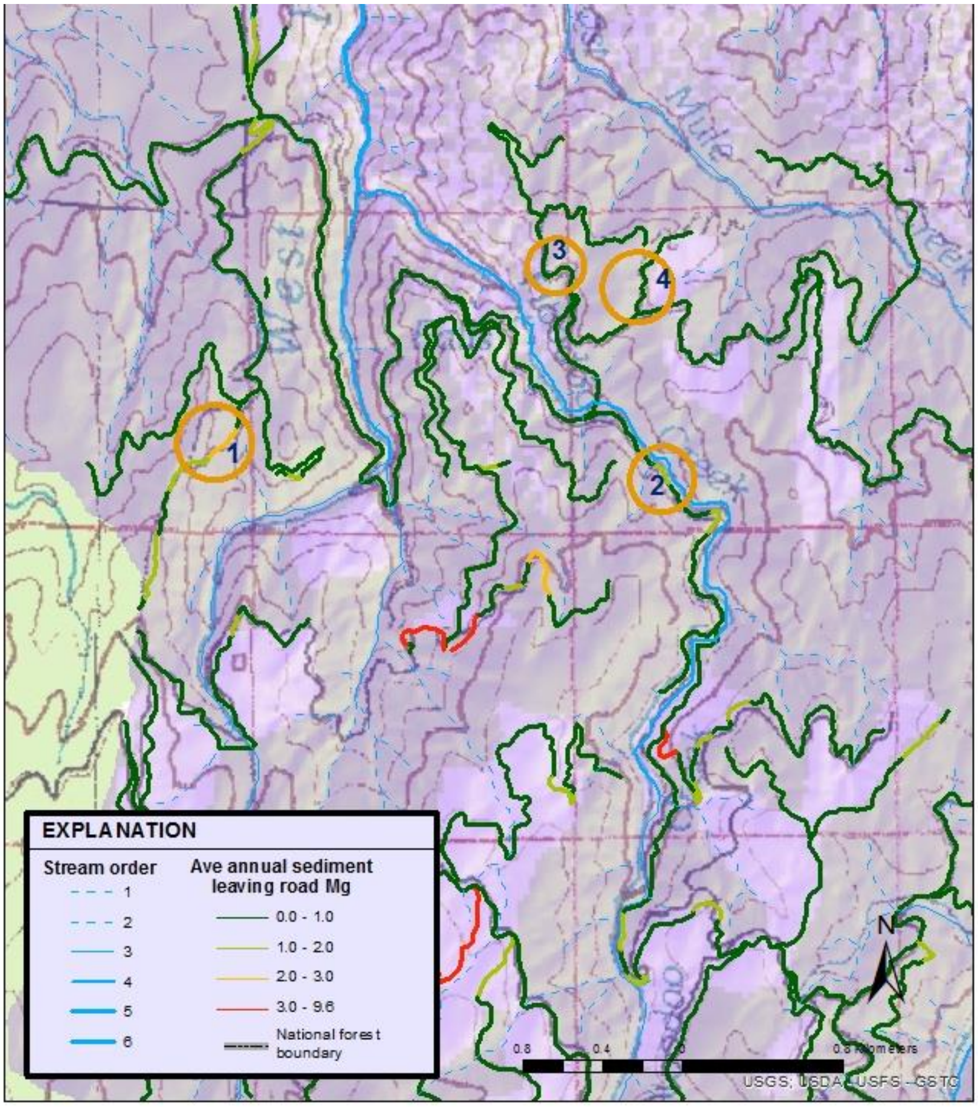

Figure 7. Location of the four sites identified for a detailed site visit in June, 2018

Sediment reduction methods including surface cross drains, graveling or ditch relief culverts are well known and applied to numerous road segments within this watershed. Identifying problem segments using sort functions with the spreadsheet or the GIS attribute tables can aid managers to quickly identify segments that may be at high risk for sediment delivery. It is, however, important to visit the segments predicted to be likely sources of sediment delivery to confirm that there is a problem. Erosion modeling can be used to aid in evaluating alternative mitigation practices for those segments found to be sources of sediment.

The field observations suggest that the total erosion predicted for the road network in this watershed is likely exaggerated. One of the roads high erosion risk roads had not been used for decades and was covered in trees, and the other high risk road that was visited had been removed from the landscape. The low use roads were all vegetated or gated, and unlikely to generate large amounts of sediment (Foltz et al., 2009). Roads that are covered in vegetation can be modeled as “No Traffic” roads in

Figure 8. Typical vegetated cover on road north of site 1. Note some evidence of ditch erosion. Similar grass cover was observed at location 3 (Figure 7).

WEPP:Road, which will reduce the estimated road erosion rate, and depending on topography and location of the road on the landscape, the estimated sediment delivery from the road. Some of these

Figure 9. Road totally overgrown with forest showing evidence of historic erosion, but no recent erosion at location 1 in Figure 7.

Figure 10. Recontoured road prevented accessing location 2 in Figure 7.

changes in road attributes can be made in the cross walk spreadsheet and WEPP:Road batch rerun for those segments.

Summary and Conclusions

The Nez Perce-Clearwater National Forest provided RMRS with their road network GIS layer. This layer was combined with a management cross walk table and a 10-m DEM to predict the sediment delivery from the road surface across a forested buffer using GIS tools, spreadsheets, and the WEPP:Road Batch

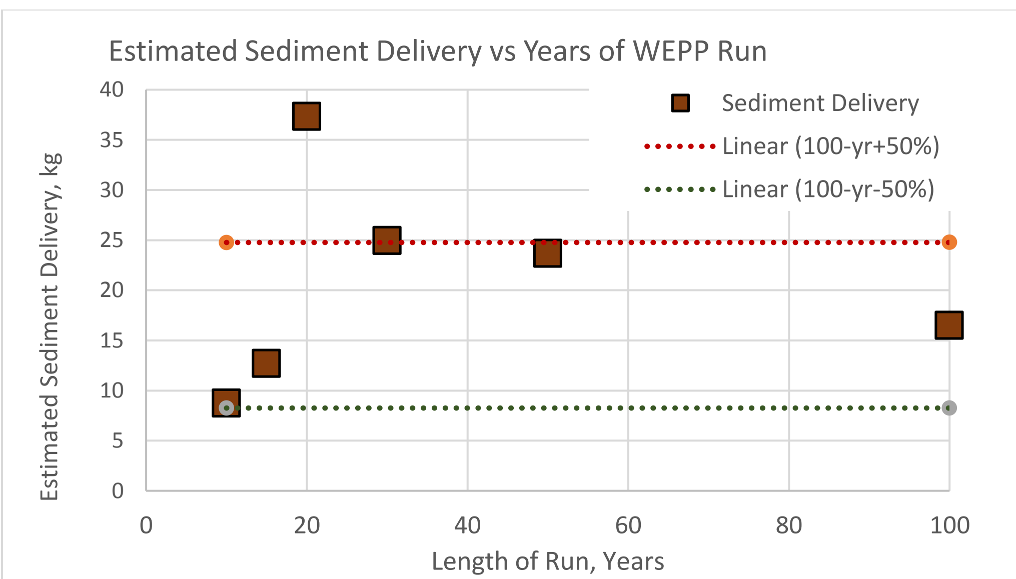

Figure 11. Estimated sediment delivery for a 60-m road segment with a 40-m buffer for different lengths of WEPP Run

interface. We delineated 3276 road segments that made up the 299 km (186 miles) of road network. Total sediment delivery was estimated to average 278 Mg (306 tons) per year. Field surveys confirmed the validity of the GIS topographic analysis, but found that some of the road segments predicted to generate the greatest amounts of sediment were either overgrown with trees, or had been removed. Further site visits can be carried out to confirm that those segments generating the greatest amount of sediment are currently eroding, and if not, the results modified to better reflect sediment generation from the current road network.

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Appendix: Files shared on the Forest Service Pinyon Drive

Link: https://usfs.box.com/s/go9hy4r4uprn1ncngqdmojkrydb80qo7

Owner: Ina S Miller (suemiller@fs.fed.us)

File Name	Description
In Road_Map_Figures Directory	
2017_CC_Road_RD-Buffer-dif.pdf	Map of road segments color-coded to reflect the difference in sediment delivered from the road and sediment delivered from the buffer. Figure 4 in this report.
2017_CC_Road_Erosion.pdf	Map of road segments color-coded to reflect the road running surface erosion rate. Figure 2 in this report.
2017_CC_Road_Buffer_Erosion.pdf	Map of road segments color-coded to reflect the amount of sediment delivered from the road less what was deposited in the forest hillslope between the road cross drain and live water. Figure 3 in this report.
In MapPackages Directory	
Three ArcMap Map Packages that were used to develop the above three Maps	The map packages can be opened in ArcMap to access the data that were used for the above three figures, as inputs to the 180815_CC_GIS_to_WRBatch.xlsx spreadsheet
Spreadsheets	
CC_roads_WEP_RdRuns_AveMg.xlsx	Summary of road erosion and sediment delivery
180815_CC_GIS_to_WRBatch.xlsx	Cross walk spreadsheet from NPC road network and a 10-m DEM to WEPP Road Batch
Using GIS to Analyze Road Erosion_OL wepp.pdf	This pdf file is the presentation that Sue Miller made at the ESRI conference in July, 2018.